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A METHOD FOR STUDYING SEISMOELECTRIC EFFECTS

A. G. Ivanov
Submitted 9 Jun 1950

[Figures referred to are appended.]

Introduction

At present, geophysicists are confronted with the complex problem of developing methods for forecasting earthquakes. Various methods of geophysical observations are used for this purpose, e.g., seismic, acoustic, gravimetric, magnetic, electric, etc.

The basic task in studies of geophysical fields in seismically active regions is the isolation of the anomalous changes in time which are of a local nature from factors of a general type which act in equal strength over a large section of the earth's surface; e.g., in connection with distant effects in the ionosphere, with general changes of the geomagnetic field, etc. The latter are usually quite intense, and it is therefore difficult to study weak changes of a field resulting from local causes when these general factors are present.

It is obvious that large changes of geophysical fields in a region where an earthquake is about to occur will proceed very slowly, since they are caused by slow changes of local elastic stresses in the earth's crust and the crust's slow deformation. The rapid perturbations of geophysical fields which may accompany slow changes, especially just before the elastic limit of the given section of the earth's crust is reached, are secondary effects of the process under study and probably have relatively lower intensity.

In this article, we discuss only seismoelectric observations.

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The Compensation Method

In the study of the seismoelectric effect of the second type (A.G. Ivanov, Izv AN SSSR, Ser Geograf i Geofiz, No 5, 1940; DAN, Vol XXIV, No 1, 1939), i.e., the emergence of electric potential differences in rocks when elastic waves pass through them, electrical interference in the earth in the form of rapidly changing currents is a great hindrance. This interference is so great that up to 10 kg of explosives had to be used at distances from 50-100 m from the observation point to excite a seismoelectric effect of sufficient intensity.

Careful study of the distribution of electrical interference over a considerable surface made jointly with A. M. Alekseyev (Izv AN SSSR, Seriya Geograf i Geofiz, No 5, 1940) showed that for observations in exactly the same azimuth, the form of interference on the oscillogram was approximately alike for two remotely separated regions and that the current changes are basically synchronous in phase.

These observations indicate first that the cause of the electrical interference is the same for the entire region studied and second that the reason is apparently connected with phenomena occurring far from the observation point. In this article, we will not touch upon the interesting problem of the nature of the effects causing this interference.

On the basis of the experiments, the author succeeded in using the compensation method to eliminate the influence of general interference. This method permitted us to increase greatly the unit's sensitivity to local seismoelectric disturbances, because of explosions.

In this method, a second supplementary pair of electrodes is installed at a great distance from the first main pair of receiving electrodes, but exactly in the same azimuth. The current oscillations from the second pair are transmitted to the input of the receiving unit in the opposite phase to the oscillations in the circuit of the main pair of electrodes. In a record case of good compensation, a clear recording of a seismoelectric effect of the second kind was obtained in the explosion of only a detonator alone (in water) at a distance of 100 m from the observation point.

Conditions Governing Use of Compensation Method in Study of Earthquake Predecessors

The use of the compensation method when we change to the study of electrical effects connected with earthquakes is complicated by the relatively greater distance from the centrum to the observation point (tens of kilometers and more). To obtain a complete compensation effect, therefore, the electrodes of the compensating line should be separated by a very great distance to fulfill the conditions required for a change from (a) the model experiments, described above, with elastic waves caused by near explosions, to (b) observations connected with earthquakes. The organization of such studies is very difficult. For these purposes, we might attempt to use continuous transmission of current changes from one point to another, not along conductors, but by radio, with the oscillations being combined at the receiving points. Such a system has not yet been devised, however.

Practical considerations force us to separate the pairs of electrodes by relatively small distances (up to several kilometers).

We assume that the electrical effect of an approaching earthquake can be represented at the earth's surface roughly by the field of a system of two charges. We place one charge in the region of the centrum at a depth h beneath the surface, and the other (of opposite sign), directly beneath it at a distance ℓ from the centrum. The charge magnitude is considered equal to one electrostatic unit.

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The values of the first and second derivatives of potential with respect to distance Δ (the epicentral distance) on the surface will then be of the form·

$$\frac{\partial \phi}{\partial \Delta} = -\Delta\left(\Delta^2 + h^2\right)^{-\frac{3}{2}} + \Delta\left(\Delta^2 + (h+\ell)^2\right)^{-\frac{3}{2}} \qquad (1)$$

$$\frac{\partial^2 \phi}{\partial \Delta^2} = -\left(\Delta^2 + h^2\right)^{-\frac{3}{2}} + \left(\Delta^2 + (h+\ell)^2\right)^{-\frac{3}{2}} + $$
$$+ 3d\Delta^2\left(\Delta^2 + h^2\right)^{-\frac{5}{2}} - 3\Delta^2\left(\Delta^2 + (h+\ell)^2\right)^{-\frac{5}{2}} \qquad (2)$$

The values for the special cases $\Delta = 0, \ell = \infty$, etc., can easily be found from (1) and (2). It is interesting to note that $E = -\frac{\partial \phi}{\partial \Delta} = 0$ in the region of the epicenter. This indicates that the ordinary observation of only the potential gradient of the earth current field at one point may not always be effective in the detection of the electrical predecessors of earthquakes. Recording of the second derivative $\frac{\partial^2 \phi}{\partial \Delta^2}$, which can be accomplished by the compensation method proposed, becomes very important in this case. We expect that such observations, in certain cases, will produce a better effect than the ordinary measurements. Figure 1 shows the curves for the first and second potential derivatives, calculated from (1) and (2) for the cases $\ell = h$ (solid lines), and $\ell = \infty$ (broken lines). Values of the ratio $\Delta/h = R$ are plotted along the abscissa.

In the "model" observations under field conditions, the elastic disturbance caused by the explosion did not reach the position of the compensating pair of electrodes. In the recording of earthquake predecessors, however, when the centrum is located at a distance comparable to the spread of the electrode pairs, the receiving unit will record the difference of the potential gradients in the two sections where the electrodes are placed, and when the electrode pairs are brought very close together, its indications will correspond approximately to the second derivative with respect to Δ of the disturbed potential. The receiving and compensating electrodes can even be moved so close together that the end electrodes will meet, and thus three electrodes can be used instead of four.

Methods and Equipment Used in Measurements

As was pointed out previously, attention must be given in the study of earthquake predecessors both to the slow, basic changes of the earth current field which are due mainly to the process preliminary to the earthquake, and to the rapid and high-frequency changes which are probably connected with the critical moment when mechanical stresses in the centrum approach the ground's elastic limit.

It is obvious that two circuit variations must be used in the electrical compensation method to solve these two problems. The use of a circuit with a filter condenser connected in series and a galvanometer of proper period is recommended for 24-hr recording on a multiple recording instrument of rapid oscillations in the band of seismic wave frequencies from about 0.2 to 2 cps. The author used this circuit in 1940 at the Andizhan seismic station.

The use of a mirror galvanometer having extra-high sensitivity is recommended for the study of slow changes of earth currents by recording the differences of the first potential derivatives or the second potential derivatives. High sensitivity is required, because the currents which result from combining (180° out-of-phase) the emf's of the receiving and compensating lines are weak. This galvanometer should also have two electrically independent loops firmly attached to the same mirror galvanometer; then observations could be made by means of the circuit shown in Figure 2a.

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If the second potential derivative is to be measured, however, we can also use a highly sensitive, single-loop galvanometer if we connect it in a three-electrode unit, e.g., as shown in Figure 2b.

It is important to keep in mind that when this method of direct recording of the second potential derivative or the differences of the potential gradient is used, electrical interference must be very carefully compensated and the receiving unit must be adjusted to the highest sensitivity for which the uncompensated interference (background) will cause, on the electrogram, currents in the form of notable, yet small, changes.

As experience in using the compensation circuit has shown, the most important condition for success is that identity in the parameters of the receiving circuits and symmetry of the circuit be preserved.

It is important to note that, along with the circuit described, the compensation method can be used in a coarser form, e.g., to eliminate the influence of changes of only the vertical component of the geomagnetic field on records of earth currents. This can be done by using horizontal ungrounded coils of wire in combination with a receiving pair of electrodes, instead of the compensating pair of electrodes.

In the study of the electrical predecessors of earthquakes by the method described, we should use two systems of receiving electrodes, recording the latitudinal and meridional components, in order to detect local electrical disturbances in any azimuth.

It would be desirable to combine these observations with A. N. Tikhonov's studies by the profile method in order to obtain more complete information on the connection of these processes with the deep structure of the earth's crust and variations of the geomagnetic field. In addition, A. N. Tikhonov, Corresponding Member of the Academy of Sciences USSR, wrote the author, while reviewing the manuscript of this work, that he had derived equations which describe the electric field in an electrically conducting atmosphere for the case of arbitrary positioning of electric charges in the earth. We expect that his calculations will also aid in quantitative interpretation of earth current observations which are made by the method cited in this paper.

In conclusion, we wish to thank G. A. Gamburtsev, Corresponding Member of the Academy of Sciences USSR, for his support in making the studies, and also Professor V. F. Bonchkovskiy, Honored Scientist, for making it possible for the author to begin work in this field in the Garm expedition of the Geophysical Institute, Academy of Sciences USSR.

/Appended figures follow/

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Figure 1

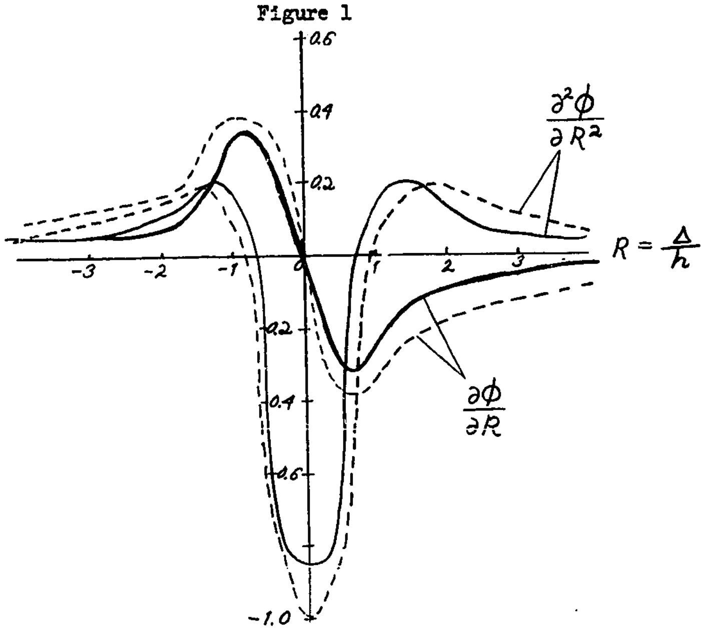
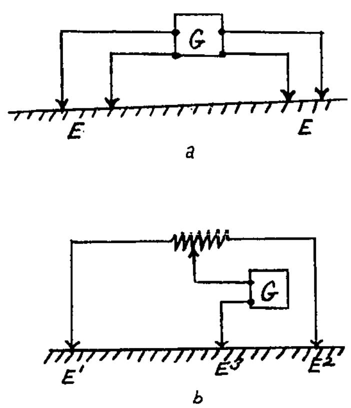


Figure 2



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